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IRRIGATION IN FIELD AND GARDEN.

BY

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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
OFFICE OF EXPERIMENT STATIONS,
Washington, D. C., June 10, 1901.

SIR: I have the honor to transmit herewith and to recommend for publication as a Farmers' Bulletin of this Department a paper on irrigation in field and garden, by E. J. Wickson, M. A., professor of agricultural practice in the University of California and horticulturist of the California Agricultural Experiment Station, prepared under the supervision of Prof. Elwood Mead, expert in charge of the irrigation investigations of this Office. The instructions given in this paper are intended for the individual farmer, not for the engineer or manager of an irrigation system.

Respectfully,

A. C. TRUE,
Director.

Hon. JAMES WILSON,
Secretary of Agriculture.

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IRRIGATION IN FIELD AND GARDEN.

INTRODUCTION.

Irrigation should be recognized as an agricultural art of very wide applicability and value. Its association with the idea of desert reclamation has blinded the public mind to its value for regions where the need of reclamation does not exist. Irrigation is a means of soil improvement to be employed, like other means of improvement, when the soil needs it. Water is the most important food of plants, not alone because it enters in such volume into their tissues, but because without it in adequate amount the plant can not use other foods in sufficient quantity. No one questions the wisdom of the saving and storing of manures, nor the wisdom of generous outlay for commercial fertilizers when required. The same is true of soil improvement by means of drainage. There should be a similar feeling in regard to irrigation.

The most diligent culture and the most generous fertilization are often made of no avail, and actual loss is sometimes incurred because the farmer has not prepared himself to supply water when needed. The water, which he could often provide for a mere fraction of his expenditure for fertilizers, often for less annual cost than the interest on his investment in underdrainage, he has neglected to have ready for use, and he sees the hope of return for his year's labor and expenditure fade away during a few weeks of drought. There have been cases where water has been stored at considerable expense as a protection against fire in barns and has remained unused while some valuable crop was burning up in the garden. Such losses are largely due to two things: First, the notion that irrigation is of importance only in arid regions; and, second, ignorance of the ease and cheapness with which a farm water supply can be stored and distributed. It is very important that the value and availability of water for irrigation should be recognized and a supply provided on each farm.

Irrigation, moreover, is not merely a recourse to insure the safety of a crop. It has been demonstrated beyond question both by prac-

tical experience and by systematic experiment that growth and production can be profitably pushed by irrigation even when the natural moisture seems ample, and in this respect irrigation aligns itself with fertilization and cultivation as a factor in intensive culture.

Another error grows out of the large scale upon which irrigation is generally known to be carried on, involving canals and ditches too expensive for individual undertaking. The impression is made that considerable capital and engineering skill are necessary to success; but as a matter of fact profitable irrigation is easily attainable by small effort. It lends itself readily to small individual or cooperative undertaking, developing water whose presence may be almost unsuspected, or utilizing water which ordinarily is either wasted or is a positive detriment when not turned to profitable service. It is the purpose of this bulletin to present suggestions for irrigation of this kind.

Small irrigation works usually require neither greater skill, labor, nor outlay than other farm improvements which are readily undertaken. They do not require as exact engineering as underdrainage by tiling, and the whole system, both for development and storage of water, often costs much less per acre of the area irrigated than does tiling. The work is more readily comparable to the construction of open drains, coupled in some cases with reservoir building, which is no more difficult than cellar excavation and is accomplished with a similar outfit of teams, plows, and scrapers. The man of ordinary skill in handling these tools, who can turn a straight furrow, or build a straight piece of fence, and can do these things well, needs only a suggestion of the feasibility of securing a home water supply for irrigation, providing his conditions are favorable.

The first thing to be done in all cases is to make a careful study of the whole situation, the location of the water supply, the lay of the land, and its requirements of water, etc.

DETERMINING LEVELS.

A fundamental requirement in irrigation on whatever scale is the determination of grades and levels. On small-scale irrigation works such approximation as can be secured by careful use of very simple appliances answers the purpose very well. Although the surveyor's level is desirable, this can be dispensed with by using the simple sighting levels described in books on drainage, and even these are not essential, for a home-made appliance can be made to give satisfactory results. Such a device is described below, which, although in constant use in some parts of the country, does not seem to be widely known. It will be found useful in nearly all kinds of farm engineering where the location of grades and levels is necessary and no special hindrances intervene, but it must be borne in mind that its usefulness depends entirely upon the care with which it is operated.

HOME-MADE LEVELING DEVICE.

The use of a leveling triangle (fig. 1) was suggested to small irrigators in California many years ago by a prominent irrigation engineer, Mr. C. E. Grunsky, of San Francisco. It is constructed in this way: The three pieces A B, B C, and C A are made fast to each other at A, B, and C. The board B D is fastened to the triangle at right angles to A C. An ordinary carpenter's square used in the construction of the apparatus will insure sufficient accuracy in the position of B D. Near B, on the board B D, a plumb line is made fast. The plumb bob, like a mason's plumb bob, hangs in a hole, so that when B D is vertical the string hangs very near the surface of the board B D. When B D is exactly vertical A C is exactly horizontal, if the angles at D are true right angles.

The dimensions of the triangle may be about as follows: A C, 12 feet long; A B, about 7 feet 3 inches; C B, about 10 feet; and B D,

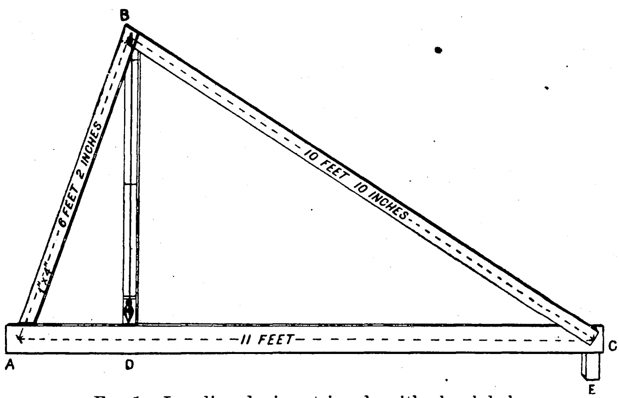

FIG. 1.—Leveling device—triangle with plumb bob.

about 6 feet long. Other dimensions will do as well, the essential features being the straight board A C and the board B D at right angles to it and near enough to one end of A C for the man carrying that end of the triangle to see accurately the position of the plumb line. The board B D should not be less than 4 feet long, or the plumb line will be too short to give satisfactory results. It will frequently be found convenient to have a scale of feet marked off on A C.

In marking on the board B D the line in which the plumb line will hang when A C is exactly horizontal considerable care is required. Two pegs are driven into the ground as far apart as A and C for these points to rest on. The highest one is driven into the ground until the plumb line follows about the center line of the board B D. Having marked this position of the plumb line, the triangle is reversed so that the end B rests on the peg where before we had the end C, and vice versa. Should the plumb line make an angle with the first line

marked on the board, then the correct position will be exactly in the middle between these two lines. This point should be permanently marked on the board B D; in using the triangle when the plumb line passes through this point the base of the triangle will be level.

DETERMINATION OF LINE OF A DITCH.

To use this instrument for locating the line of the ditch, calculate the amount which the grade should rise in a distance equal to the length of the base of the triangle to secure the fall which is best to convey the water, according to character of soil, etc., a matter which will be discussed later. Under one end of the base fasten a small block with a thickness equal to the desired rise. Below is given a table, showing the thickness of blocks which should be used on triangles of different lengths to give various grades.

Amount of fall secured and thickness of blocks required with triangles of several lengths.[1]

Length of base of triangle.	Thickness of blocks, being the amount of fall for different triangles and for different grades, per mile.						
	4-foot grade.	5-foot grade.	6-foot grade.	7-foot grade.	8-foot grade.	9-foot grade.	10-foot grade.
Feet.	*Inch.*	*Inch.*	*Inch.*	*Inch.*	*Inch.*	*Inch.*	*Inch.*
10	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{1}{4}$
11	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{1}{4}$
12	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{1}{4}$
15	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{5}{16}$
16	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{3}{8}$
$16\frac{1}{2}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{3}{8}$

[1] The numbers 4 to 10 at the head of the columns are the number of feet of fall in the ditches per mile of length. The fractions below these numbers give in inches the fall which must be allowed in the length of the triangle. These are correct to the nearest one-sixteenth of an inch.

When a block of required thickness to give the desired grade has been fastened to the triangle, drive a peg at the starting point with its top, say, 6 inches from the proposed bottom of the ditch. Place the end of the leveling apparatus under which the block is fastened upon this peg, with the other end pointing in the general direction from which the ditch is to come. The bottom of the block must rest upon the top of the peg. Bring the apparatus to a level and set a peg 6 inches long so that its top just touches the bottom of the forward end of the apparatus. The lower end of this last peg will then mark the bottom of the proposed ditch. This operation will be simplified by putting a leg just 6 inches long upon the forward end of the triangle. It will then be only necessary to swing the triangle around until the base is level, when this leg will rest upon the bottom of the proposed ditch. Drive a peg here, which will, like the first, be 6 inches high from the ditch bottom, carry the triangle forward to this peg, and proceed as before.

Contour lines for checks or distributing ditches can be located with

the aid of the triangle. To locate a contour line (a line passing through points of equal elevation), as required in the construction of a check levee, drive a peg until its top has a convenient elevation from the ground, say 1 foot. Put a leg of equal length on one end of the triangle and rest the other end on the peg, then swing the triangle around until the plumb line shows the base to be level. At this point drive a second peg and proceed as before. If the pegs are driven so that the tops are at the height of the proposed levee they may be retained as grade stakes as well as line stakes for the embankment.

To find a point in the next contour line below, on which a check levee should be raised so that its embankment will hold back the water to the base of the higher one, begin with the end A at the base of the upper levee and level the triangle in the direction of the proposed levee, measure the distance from the end C to the surface; from this point use the triangle again in the same way and repeat the operation until the sum of all the measurements made from C to the surface is equal to the height of the levee it is intended to construct. Having thus found a starting point for the second contour line proceed to locate this line as before.

It is obvious that the triangle is most serviceable in determining grades on land which has considerable slope, because more appreciable differences in grade will be noted in each use of its length. The difficulty of reaching correct conclusions as to the best position for a ditch or contour check increases, as a rule, with the flattening out of the surface. But the use of the triangle is only recommended for small-scale work in the absence of more accurate instruments, and under such conditions it is very serviceable.

MEASUREMENT OF SMALL STREAMS.

Before discussing sources of supply it is important to cite a method by which the quantity of water available in a small brook, outflow from a large spring, or discharge from a drainage system may be easily ascertained. Without an estimate of the supply, reservoir building or the determination of the area which can be irrigated is merely guesswork. Recourse to the miner's method of measurement is best for such sources as will frequently be drawn upon for the farm supply. It consists in causing the water to flow through an opening, the capacity of which is known, and which is readily capable of adjustment to the flow in any case.

A simple form of this device and its use is shown in fig. 2. The illustration represents a board 1 inch thick, 12 inches wide, and about 8 feet long. The opening is 1 inch wide and 50 inches long, and the distance from the top of the board to the top of the opening is exactly 4 inches on the upstream side. On the downstream side the opening is beveled so that the hole presents sharp edges to the stream. A

sliding board is hung upon the top of the first board with a strip screwed along its upper edge, this sliding board being wide enough to cover the opening on the upstream side. In the slot there is a closely fitting block made to slide on the beveled edges, and fastened by a screw to the sliding board. It is obvious, then, that when the sliding board is moved backward or forward, by means of its end, which is extended for a handle, the block moves in the slot and determines the length of the opening.

In operation the board is placed in the stream as shown in the figure, so as to dam the flow completely, and the sliding board is moved backward or forward until the water is all passing through the slot, the water being kept up to the top of the board, or 4 inches above the top of the opening. The length of the opening measures the number of miner's inches of water flowing through. If the flow

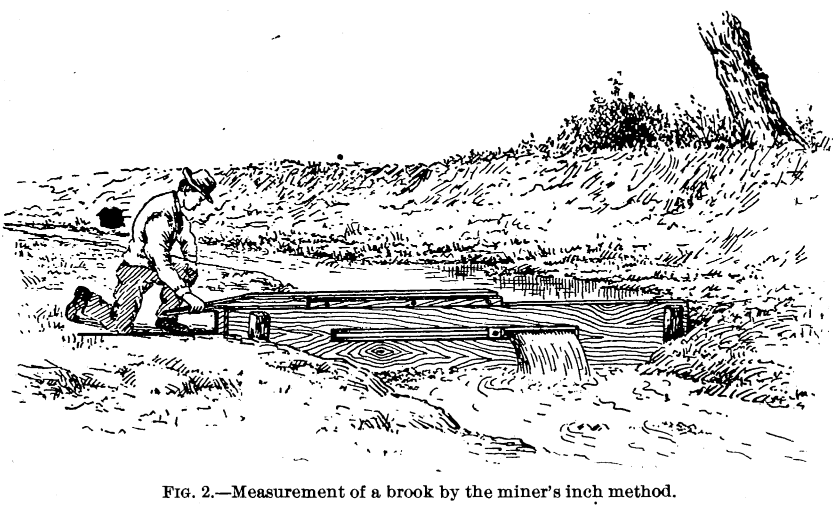

FIG. 2.—Measurement of a brook by the miner's inch method.

is too great to pass through the opening 1 inch wide the opening may be made wider, the water still to be kept 4 inches above the top of the opening. The laws of several States provide that in devices for measuring water for sale by the miner's inch the opening shall be 6 inches high, and shall be provided with a slide as shown in fig. 2. The number of miner's inches then discharged is equal to the number of square inches in the opening. The assumption made that the discharge is proportional to the size of the opening is not true, but the error in measuring small quantities is not great enough to be taken into consideration. By converting the results of measurements in miner's inches to gallons, cubic feet, or some other familiar unit, it may be determined how long it will take the stream to fill a reservoir or cover a given field with the necessary depth of water. This unit is readily convertible into cubic feet or gallons or acre-inches of water, according to the time the water flows.

The following data will be helpful in computations: One miner's inch, as described above, equals 0.1496 gallon per second; 8.976 gallons per minute; 538.56 gallons per hour; 12,925.44 gallons per day; 0.02 cubic foot per second; 1.2 cubic feet per minute; 72 cubic feet per hour. One acre-inch of water (that is, 1 inch in depth over an acre of surface) equals 27,152 gallons, or 3,630 cubic feet, and 1 miner's inch will supply this quantity in about 50.4 hours. Thus a simple calculation shows that a little stream of 5 miner's inches will supply enough water to cover an acre 2.3 inches deep in about 23 hours—a fair amount for one irrigation of soil of average character if it has not been allowed to become too dry before the application;[1] in fact, this is an average amount actually used for an irrigation of shallow-rooted plants like most field and garden crops.

SOURCES OF WATER SUPPLY AND THEIR USE.

The sources of water supply and methods of use most frequently available for a single farm include the following: Diversion of perennial streams; development in dry stream beds; development of springs; catchment from outcroppings of water-bearing strata; tunneling to intercept such strata when deeply covered; flowing wells; pumping from wells, lakes, or streams, and storage of storm water from surface flow or from drainage systems.

DIVERSION FROM STREAMS.

Diversion from perennial streams is the most common method of securing irrigation water, and it is available for either great or small undertakings wherever unappropriated water flows in sufficient amount. In the regions where irrigation is most widely practiced there may no longer be such supplies available, but in the newer parts of the arid region and quite widely in the humid regions, farms are so situated that stream water can be readily secured.

After assuring himself in the manner described that a near-by stream carries sufficient water for his purpose, the next step for the farmer is to determine whether the water can be brought to his land at a reasonable expense. This will depend principally upon the length of the ditch which must be constructed. The simplest way to find out how long the ditch must be is to run a line having the necessary grade from the highest point of the land to be irrigated upstream till it strikes the stream. The grade on which the ditch should be built, and consequently upon which this preliminary line should be run, will depend upon the quantity of water to be carried and the nature of the soil over which the ditch will run. In general, the larger the ditch and the lighter the soil the smaller the fall which can be given to the ditch;

[1] For the water capacity of different soils see U. S. Dept. Agr., Farmers' Bul. 46, p. 14.

and the shorter the ditch the smaller the fall. However, the grade should not be too light, for the ditch may have to be made larger to carry the desired supply of water. On the other hand, the grade can not be very heavy or the strong current will wear away the ditch banks. Therefore the range of the grades which may be given to a ditch is limited. In ordinary soils a grade of 2 inches in 100 feet may be given to small ditches, and in clay soils as much as 3 to 5 inches in 100 feet may be given.

Should the line run in this way be too long, the stream below the point where the line strikes it should be examined to see if there is any place where the water can be raised by a dam high enough to flow into the proposed ditch. In case no such place is found, a water supply from that source must be abandoned. If this preliminary line shows that the water can be brought to the land by a reasonable expenditure of labor and money, the ditch line should be carefully located as before described (p. 8).

It may be that the place where the line strikes the stream is not a convenient place for diverting water. In such a case the head of the ditch may be moved upstream, and a drop put in to avoid too heavy grades, or the head may be moved downstream and the water raised to the ditch by a dam.

BUILDING THE DITCH.

Having decided upon the point of diversion and located the ditch line, the farmer is ready to build the ditch. Experience in making drain ditches will help in this. But there is this difference: Drain ditches must be kept in the ground as deep as practicable, while irrigation ditches must be kept as near the surface as may be, in order that the water can be easily taken out. The line of the ditch should first be marked by a furrow. To do this, let one man guide the team, walking between the heads of the horses, holding a bit in each hand, while another holds the plow. If the surface of the ground is such as to permit a wagon to pass along the line, the plow may be attached to the rear axle, the driver directing the team from the seat of the wagon. The furrow should be turned to the lower side of the ditch. If the surface of the ground is comparatively level across the line of the ditch, it is not necessary to follow the stakes closely in the bends. The ditch will be better for being straightened a little, which may be done by going above the stakes that locate the bends nearest the stream and below the stakes farthest away. If the ground slopes very much across the ditch line the stakes must be followed closely. After the line is marked, two or three furrows are plowed, all being turned to the lower side. A farm ditch can be made almost wholly with an ordinary plow by going over the line a number of times. The loose earth in the bottom of the ditch may be removed with a scraper or shovels.

A small stream can be easily diverted into a ditch, if it is running

in a shallow bed, by a cross-stream dam of posts and plank, of posts and brush, of brush and rock or cobbles, etc. (fig. 3). Such structures are not usually water-tight, but they will raise the water to the level of outflow into the ditch which is to carry it to the land to be irrigated

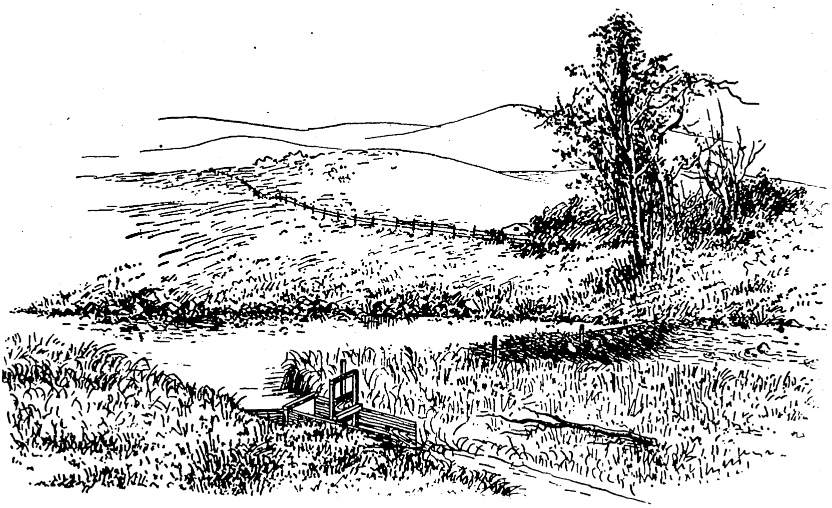

FIG. 3.—Diverting a small stream, showing brush dam and headgate.

or to the reservoir (fig. 4) from which it is to be distributed. A better dam, either of masonry or of earth, made water-tight by a puddle bar of clay, may last for a long time in a small stream if adequate arrangements are made for the passage of waste and flood water.

Raising a small stream in a deep bed requires a dam of greater strength. In such cases it is safer to make the dam of timber or

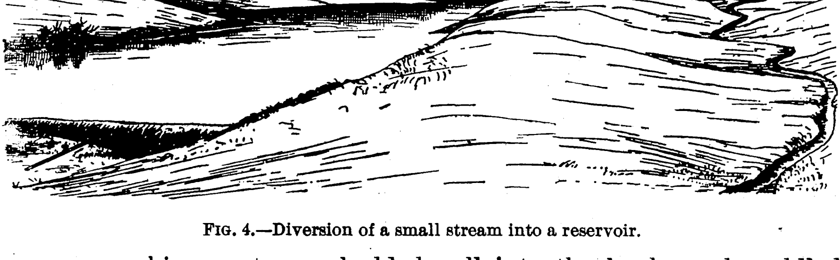

FIG. 4.—Diversion of a small stream into a reservoir.

masonry arching upstream, bedded well into the banks, and puddled well above with clay, to prevent leakage, which would soon undermine and carry down an otherwise good structure. Such a dam will cause the bed of the stream above it to fill with sediment, which will reduce

the direct pressure. The beginner, however, will do well to err on the safe side, if at all, and make his dam twice as strong as might seem on first thought to be necessary.

In a wider stream in a shallow bed enough water can often be diverted by a wing dam, starting just below the head of the ditch and running obliquely up the stream toward its center. Such a dam can be easily constructed of posts and brush, or of any coarse, heavy material which is ready at hand or most cheaply secured. It raises part of the water sufficiently for outflow into a ditch and is not enough of an obstruction to be torn out in high water, or, if the dam is partly destroyed, it can be cheaply replaced.

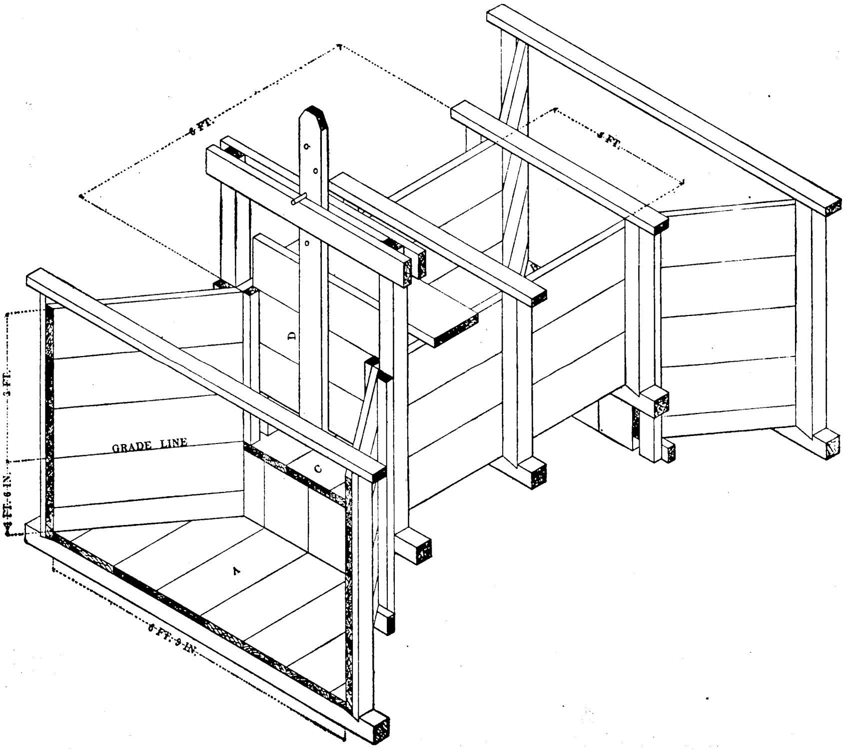

FIG. 5.—Details of a headgate.

At the point of diversion from the stream a head gate should be put in. This is a very simple construction of plank with a sliding gate capable of being raised and lowered. It will protect the ditch by keeping the water out in time of high water. It should have a cross plank on the stream end, so that the water shall fall over the plank, as this will prevent much heavy sediment from entering the ditch. Obviously the dam must raise the water sufficiently to surmount this obstruction. The accompanying drawing and description of a small head gate are taken from the Yearbook of the United States Department of Agriculture for 1900.

Fig. 5 shows a common type of small headgate. It consists of a box or flume 6 feet long, 3 feet wide, and 3 feet deep, with a gate (D) at the end nearest the creek. At both ends the sides flare at an angle of about 30 degrees. Under them, 1½ feet below the floor of the structure (C), platforms (A and B) are built. Both of these platforms are covered with earth to the level of the floor (C). Earth is also carefully tamped around the outside of the headgate.

All precautions should be taken to prevent water from working along the outside of the headgate. The structure may be undermined in a short time if only a small stream finds its way between the planks and the earth. The flaring wings and submerged platform are built to prevent this action, and also to make the structure secure in case of high water.

DEVELOPMENT OF WATER IN DRY STREAM BEDS.

Development of water in dry stream beds is a frequent recourse where the bed is largely composed of sand, gravel, or rock débris of various kinds. In the arid region especially the visible stream is often only a fraction of the water moving along a stream bed, and when no water is in sight there is frequently considerable underflow during the dry season. On large streams water enough has been intercepted to supply large irrigation enterprises, and in many cases a small stream will yield a valuable farm supply.

The first thing is to determine by a prospect in the dry season whether an underflow exists when the surface flow has ceased. Select a point in the stream bed where it seems to be confined to a deep, narrow channel, as well as can be judged by the steep, rocky banks, and excavate a hole or well down to water and open out the bottom so as to obtain a water surface like that in a well. By observing this it can be determined whether a water pocket or an underground stream has been struck. In case of a stream the movement can be detected by the collection of light litter, etc., on the downstream side, or, in case of a considerable movement, the flow of the water can be detected by the action of the lighter sediment. If no movement can be detected, the effect of pumping from the hole will give an idea of the amount of water available by the length of time the hole will stand pumping.

Supposing the prospect is promising by the tests applied, the stoppage of underflow by a submerged dam is the next step. To construct this an excavation must be made across the stream bed to rock or hard clay on the banks, and must be carried down to bed rock or hardpan at the bottom of the channel. Ordinary precautions against caving of the sides of this wide trench must be taken according to the nature of the material found. The water must be temporarily dammed and forced to flow through a pipe or box. Then the closest possible contact must be secured by effecting a lodgment in impervious material at the sides and bottom, and the dam should be constructed of concrete rich in cement, the upstream face being well plastered with cement or with a coating of asphaltum, if available. When the work has set

well, the temporary escape of the water may be stopped and the loose material replaced on both sides of the dam. The top of the dam usually rises sufficiently above the stream bed to hold back a certain depth of visible water (fig. 6), and to deliver it at a level where it can be conveniently taken into a pipe or flume and carried to a ditch below, where firm ground is reached. Of course the water can often be taken out by an underground pipe from a low point in the dam if the grade to the point of use is sharp enough.

Holding water by a submerged dam has advantages. It employs a subterranean reservoir and largely reduces loss by evaporation, which is so great in surface storage. It is also a reservoir presumably with tight sides, else the prospect would not have shown sufficient water to impound. It is a safe dam, because it offers no resistance to freshets.

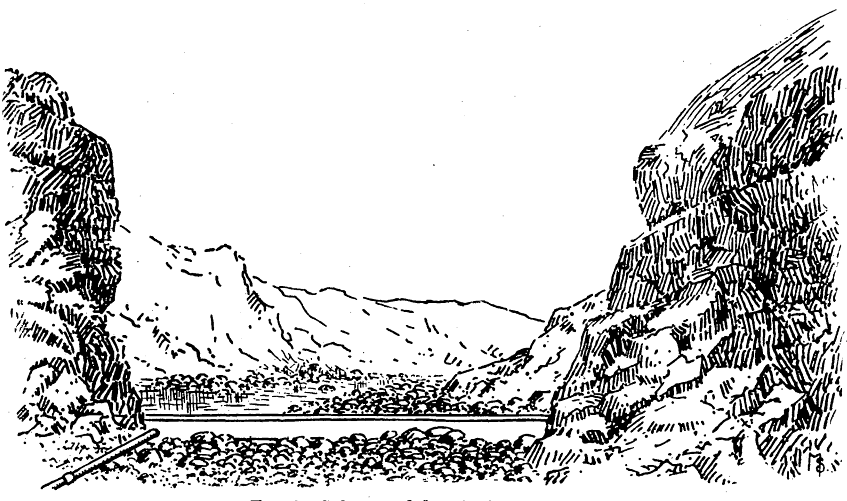

FIG. 6.—Submerged dam in dry creek bed.

If it lacks elevation for outflow, it serves as a fine cistern for pumping, and conserves water for that purpose. A point of excellence in a submerged dam is its perfect bedding and construction so as to be water-tight. This is not always attained, especially when the attempt is made to intercept a wide valley stream without definite banks, and some submerged dams are not as efficient as calculated upon. In work on a small scale it is not advised to try any experiment with such a source. For the farm supply the underground stream should be comparatively small and well confined on both sides.

DEVELOPMENT OF SPRINGS.

The opening up of springs is often a very satisfactory means of obtaining a farm supply of irrigation water. Their development sometimes consists in the excavation of a reservoir in a piece of springy or marshy ground, or in laying underdrains to take their flow and connect-

ing them with a more convenient reservoir site at a distance. Sometimes a spring whose flow can not be recovered from the area of boggy ground below it can be opened up and its water readily directed to a single channel, or to a pipe leading to a reservoir (figs. 7 and 8). By

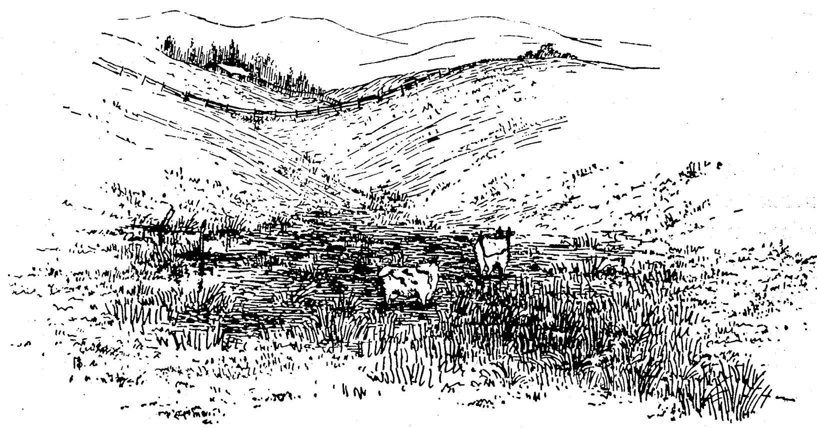

FIG. 7.—A bog hole caused by water from a spring.

this means waste land, which is both useless and treacherous, is reclaimed and made productive, while at the same time the waste water which destroyed it is utilized to make other lands more productive.

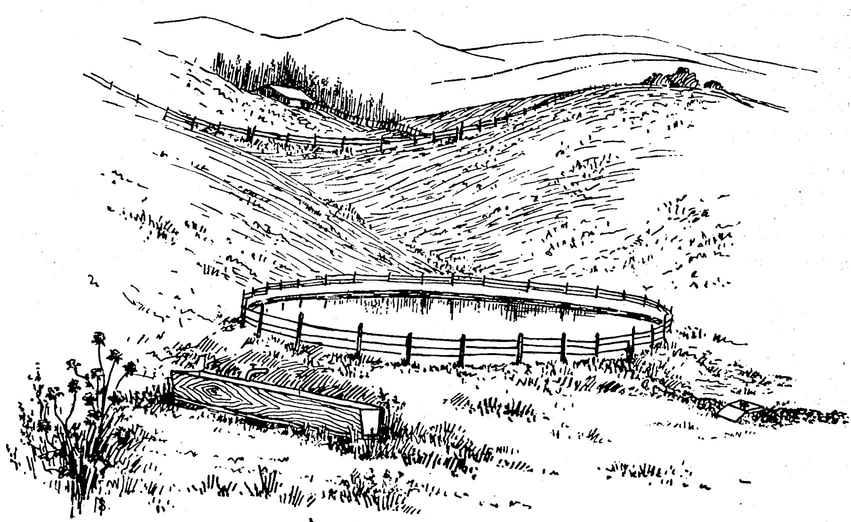

FIG. 8.—Bog hole made to yield clean water for stock and irrigation.

Many farms have blemishes of this kind to be removed, and long and costly channels are cut merely to provide an outflow to a water course. It would often be less expensive to include a system for irrigation, and thus to double the return for the necessary expenditure. Foul mud

holes, which are maintained for watering stock, can be made to yield a wholesome water supply for stock and an irrigation supply for the farm garden by piping from the reservoir which can be constructed on the site of the old mud hole at a little cost. All these improvements can be accomplished by the ordinary methods and materials for underground drainage, and therefore need not be further discussed in this connection.

There is, however, one matter in connection with a projected utilization of a spring or any small outcropping of water to which careful attention should be given, and that is approximate knowledge of the amount of water which can be made available. This may be obtained before investment of labor or material is made by opening up the spring thoroughly, cleaning it out to expose its outflow, and measuring the flow in a water-tight basin or a vessel of known capacity. Note the time required to fill the vessel, and it can be quickly calculated how much the spring will yield in twenty-four hours. Almost everyone will be surprised at the result of the measurement; a trickle of water thought to be too insignificant for consideration will be found to yield a very effective continuous flow, if the water is collected. A 5-gallon oil can is a handy measure. Suppose the spring fills it in two minutes, the yield would then be 3,600 gallons in twenty-four hours, or 108,000 gallons in one month, and this amount is equivalent to nearly 4 inches of rainfall on an acre of ground. Such an amount, if carefully collected and applied, would keep a garden of small fruits and vegetables in good growth, even with very little rainfall, if the soil be of fairly retentive character; as a safety supply against the short droughts of the humid region it would rescue a crop which might be worth several hundred dollars.

Thus a little outflow from a spring, which might pass away unnoticed underground or at most by surface flow would only make a sedgy streak across a corner of a field, can be made a potent factor in production. Of course, in handling water from such a small source of supply it must be constantly protected from loss. It would disappear in an open ditch in a short time. Usually it must be conveyed in a pipe to a tank or tight reservoir and collected in sufficient volume to cover quite an area at each application.

COLLECTION OF WATER FROM SIDES OF CANYONS AND RAVINES.

In the same class with development of springs is the collection of water from banks in canyons or ravines where floods have uncovered water-bearing strata. Water seeps out on these surfaces and sinks away in the débris which is usually found in such places, reaching at length the stream bed and passing away as surface flow or underflow, according to the character of the stream bed. Sometimes, where the

difficulty of making the submerged dam is too great, the outcropping from the bank alone may yield as much as a good spring and be secured by cutting out a ditch at the bottom of the bank, cementing it or clay-bedding it well or bedding in a plank box and connecting by a pipe with a reservoir in the same way as in case of a spring.

TUNNELING FOR WATER.

Tunneling to intercept water-bearing strata is frequently resorted to. Such tunnels have been aptly called "horizontal wells." In California thousands of them have been carried into hillsides to secure water for irrigation and for domestic uses, both in town and country. Outcropping of water at the bases of slopes, or at the mouths of depressions connecting hillsides, often suggests tunneling. The purpose is to cross the strata inclining toward the tunnel, and any available suggestion as to the dip of the strata in the hill, from seepage or otherwise, is important.

The writer knows of a case where several tunnels were run into a hillside at different points and none of them yielded in satisfactory amount, though carried several hundred feet into the side of the hill. Afterwards it was noticed that the base of the other side of the hill showed springs, while the side which had been tunneled showed none. The owner on one side lost all his investment in tunneling, while the owner on the other side secured all the water by merely opening springs, because the strata on the hill inclined his way. Tunneling is, therefore, not a sure way to get water, and some horizontal wells may be as dry as some vertical wells.

Again, there may be a quick rush of water into a tunnel which will drive out the workmen and almost as quickly cease. In such a case a sort of water pocket or the upper part of a water stratum is pierced and its supply soon drawn off. And yet many tunnels are very satisfactory and enduring in their flow. One of considerable length is known to the writer, the mouth of which was walled up by the owner, an iron pipe and valve being securely bedded in cement mortar, and the tunnel made to constitute an underground reservoir as well as a source of supply, the water being drawn off as desired for domestic use and for garden irrigation. Drifting and timbering are involved in this line of water development, but they are not easily understood, and skilled workmen are necessary for such construction.

FLOWING WELLS.

Flowing wells are largely employed for irrigation in regions where such a supply can be secured. Their cost and availability are quite fully understood in those regions. It must be said, however, that although constantly flowing water, at a proper elevation for distribution by gravity, would seem to be an ideal source of supply, it is not an

unmixed blessing unless properly controlled. Proper control, by impounding in a reservoir or by capping the well so that its flow can be stopped when there is no immediate use for the water, is essential. In great enterprises the flow can be constantly used and the wells can gush unceasingly, but on the farm flowing water in excess of needs is apt to destroy much land. Again, a small flowing well such as can be cheaply secured in some places is apt to cease to flow in a time of protracted drought, just when its flow is most desirable.

The behavior of this class of shallow flowing wells is shown by recent experience in parts of California in which there have been three successive years of deficient rainfall. There are belts where there has always been until this drought a flow from small artesian wells, which are chiefly used for domestic and stock purposes; and, as the ground water was near the surface, the crops and trees were trusted to do their own pumping if they needed more moisture than rainfall afforded. During this drought these wells ceased to flow, and the ground water sank too low for the shallow root system of the trees, and out of reach also of the roots of field crops. Alfalfa fields died out, not because the water was out of reach of alfalfa plants trained to seek their own supplies, but because the usually high ground water discouraged deep rooting, and the sinking of this water left the plants high and dry and dead. Hundreds of acres of rich land were bare and desolate, although the water stood but 7 to 10 feet below the surface. This seems almost incredible in view of what has been recently learned of cheap pumping. It was the freely expressed local opinion that these flowing wells had proved a curse. If the water had never flowed their owners would long ago have had recourse to pumping. If it had never flowed, there would not have been the increase of alkali due to surface flooding from such wells, with not volume enough to carry the alkali away below.

But while this is true, there are also flowing wells of great output and of enduring flow, which are rendering thousands of acres of arid land productive. Such full information on the subject of artesian wells, both those which flow and those which require pumping, is so easily available in the publications of the Department of Agriculture[1] that further discussion is not necessary here.

PUMPING FOR IRRIGATION.

Undoubtedly the most interesting and important phase of recent progress in irrigation practice is found in the use of the pump as a source of supply. Wonderful results have been achieved in increasing the efficiency of pumps and motors and reducing their cost of operation. Individual owners have often secured water by boring or digging wells

[1] Notably in the Reports to Congress on the Artesian and Underflow Investigations, 1892.

and the use of a pump for much less than they could buy it from ditch companies and thus are enabled to use more water and at more convenient times with less outlay. For this home supply all sorts of wells and all kinds of pumps and motors are being used, according to local conditions of subterranean water-bearing strata and local power supplies. The subject is too wide and varied for discussion in this place. It should be studied with the help of the best local well borers and mechanical engineers and mechanics.

Several things are now very clear, viz: That the capacity of all openings into underground water should be tested by pumping to determine what is the available supply; that, this being known, the motor and pump should be adapted to the supply by a competent expert and purchased under contract that they shall actually perform the service contemplated with the specified cost of fuel; that there is such great difference in efficiency and working cost between the modern pumping outfits and those of even a few years ago that one can not afford to accept an old-style outfit even as a gift; that makeshifts of discarded thrashing engines and second-hand pumps are too great an extravagance to be indulged in. These suggestions apply of course to all sources of pumped water, including wells, lakes, and streams.

The development of pumping from local sources of supply has not only made individual farmers independent of distant supplies, but it has led to the organization of many neighborhood cooperative undertakings which are proving very satisfactory, and has led also to traveling pumping plants, on wheels and on flat boats. All such undertakings seem to be satisfactory when they are up to date in machinery and methods.

On many farms there are already wells with windmills and pumps, for supplying water for stock, which can be utilized to raise a good garden of vegetables and small fruits, or to save a garden crop in a short season of drought. Either the mill is shut down much of the time or the water is allowed to waste onto the ground around the watering trough. The only added investment necessary in order to use this waste is for a tank or reservoir to hold the waste water until enough has accumulated to be of use. The water from an ordinary pump will flow but a few feet from the well if allowed to run on the ground, but if it is collected in a tank or reservoir, and run out in a good-sized stream, it can be carried for a considerable distance, even in an open ditch, and much farther in a pipe or trough, and can be made to water quite an area of garden.

STORAGE OF STORM WATER.

A good supply of water for irrigation can sometimes be secured by collecting and storing the run-off during storms from lands lying higher than those to be watered. Such a source of supply is obviously

less trustworthy in an arid than in a humid region, because of the smaller rainfall, the greater evaporation, and the length of time the impounded water must be exposed to loss from that source. Under such conditions reservoirs simply for storing storm waters are often not worth their cost. In regions having heavy summer showers it may be very different, because a comparatively short time may intervene between the falling of the water and the occasion for its use. Storm water is collected by damming a ravine or dry run which carries the water running off from the higher lands, and storing the water either in a reservoir formed by the dam or in a reservoir constructed out of the course of the stream to which the water is conducted through a ditch heading just above the dam.

The impounding of water by means of a dam across the mouth of a small ravine or canyon is often feasible, and quite a pond may be secured by a few days' work with plows and scrapers; or a swale through which the stream passes may be scooped out into a reservoir. In such work, however, one must know fully the character of the stream and the area of its watershed, and not undertake to restrain a stream of great flood power, though it be but rarely manifested. Such work has led to great injury to lands and improvements below.

Aside from such dangers, there are at least two objections to creating a reservoir in the bed of a stream. One is the chance of leakage; another is the rapid filling of the pond by the sediment carried by the flood water, thus decreasing the capacity of the reservoir. Stopping the mouths of ravines is open to both these objections, and is also disappointing, because in most cases much less storage capacity is secured than is expected, unless the dam be raised quite high, and this multiplies cost and danger with great rapidity. It is seldom desirable to enter upon such undertakings without competent engineering advice. For these and other reasons the reservoir for storm water, as for the gradual accumulation of a small flow, should in most cases be located out of the course of the stream.

Small reservoirs in connection with farm irrigation works are desirable, from many points of view, and in making use of small runs of water are indispensable A small stream allowed to flow constantly, no matter from what source, is of almost no use for irrigation, because it will not flow any distance when applied to the ground. But by saving the water in a tank or reservoir a strong stream can be made available for a short time, and will spread over a considerable area. The advantage and the cheapness with which such reservoirs can be secured need not be enlarged upon in this connection, for full attention has been paid to them in other publications of this series.[1]

[1] U. S. Dept. Agr., Farmers' Buls. 46 and 116, and Yearbook for 1896, p. 187.

DISTRIBUTION OF IRRIGATION WATER.

For the conveyance of water from the source of supply to the ground to be irrigated, as well for its distribution thereon, the ditch is the prevailing agency. The laying out and construction of ditches has been already discussed.[1]

Their obvious advantages are cheapness and durability. The chief disadvantage lies in the loss of water by evaporation and seepage. Where the water supply is scant and where the soil is so open that the loss of water by seepage is likely to cause injury to good land on lower levels, the saving of these losses may justify the expenditure necessary to prevent seepage by paving or cementing the ditch, or to insure delivery of water without loss from any cause by the use of a pipe line. These are usually questions connected with large irrigation enterprises rather than with the use of a farm supply, and yet they sometimes arise in connection with the latter. In regions where the ground does not freeze a thin coating of cement or asphaltum on well-made ditch banks and bottoms will prevent all losses from seepage. Where flat stones are plentiful, they are readily made into a stone ditch with cement mortar. Such ditch linings are, however, liable to be upheaved by freezing and are safe only in moderate winter climates.

The board flume is upon the whole the most available recourse when the simple open ditch will not answer, and the cheapest flume for carrying a small stream of water is the V-shaped trough of two wide boards nailed together along two edges and bedded in the soil with short cross-pieces under the end joints. This prevents loss of water by seepage, reduces friction, and delivers the water rapidly with a very slight fall and escapes the erosion of a dirt ditch if the slope is sharp. Even where the water must be carried over an uneven surface in a flume supported by stakes and cross pieces, the bedded V flume is still desirable for the parts where a good grade in the earth can be found.

The various ways in which water is distributed for the growth of fruits, according to the slope of the ground and character of the soil, have been discussed in such detail in Farmers' Bulletin No. 116 that the reader is again referred to that publication. The principles and practices there presented are also of wide applicability to the use of water for field and garden crops, and should be considered therewith.

Distribution by a system of underground pipes with standpipes, hose, and sprinkling devices is not widely practicable, because of the cost of the outfit. It is true that in intensive horticulture the return may be so great from a small area that the investment may be found profitable, but such investment is out of the question for common crops, and the cheaper way secures a welcome saving in the cost of

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[1] See also Yearbook U. S. Department of Agriculture, 1900, p. 492.

production of even the highest-priced commodities. One must be quite sure of his market when he makes large investment in facilities for production, and the fact that market gardeners and small fruit growers in irrigated regions never resort to the showering method is a demonstration that the risk involved in such large investment is unnecessary. For the growing of home supplies or commodities for sale in low markets the investment required for showering would practically prohibit resort to irrigation.

LOCATING THE FARM DITCH.

Contour lines are prime factors in all systems of distribution of water by natural flow, or, as they are commonly called, gravity systems. For this reason pains should be taken even in small undertakings to mark out these lines with approximate accuracy. The use of the triangle for work of this kind has already been suggested. From the highest point on the land to which the water can be brought the main supply ditch should be laid out as nearly along a contour line as will give sufficient fall for the water to flow. If this main ditch be carefully laid out and well made the water can be taken out and carried by lateral ditches or flumes along lines of nearly equal elevation in any direction in which there is a slope away from the main ditch, or it may be dropped from the main ditch through pipes or wooden flumes to lower lines or ridges from which distribution can be made.

By studying the relations of the different surfaces, or irrigation faces, to each other and correcting visual impressions with the use of the triangle, the farmer can carry the water to every point of a very uneven piece of land and successfully avoid both cutting and overflow throughout his whole system of ditches and flumes. This is done by getting even grades and the least fall which will move the water. The general tendency is to give ditches too great a fall.

DEVICES FOR TURNING WATER FROM DITCHES.

The crudest way to turn water from a ditch is to make a cut in the side with a spade and throw the dirt into the ditch to make a dam. Some simple home-made devices will obviate the manifest disadvantages of this method. Three will be described, and others will suggest themselves to the ingenious irrigator.

The cloth dam (fig. 9) is very widely used. It consists of a rectangular piece of stout, closely-woven cloth or canvas, one side of which is rolled around and nailed to a crosspiece of wood of length and strength according to the size of the ditch and the amount of water to be dammed. Sometimes it is made with a hem across one side deep enough to allow the crosspiece to be thrust through the hem. In using the dam, place the stick across the top of the dry ditch where it is desired to throw the water out; draw the lower edge of the cloth up the bottom of the ditch and place a little dirt on the corners. (See

fig. 12, p. 27.) The canvas must always be large enough to have several inches lap against the sides of the ditch; otherwise it will not retain all the water. Should the ditch have a steep grade it will be necessary to let the canvas fill up gradually, as a sudden rush of water would force the cloth from its position. When the dam is in position it will be necessary to cut the bank of the ditch at the places where the water is wanted. Two cloth dams will be needed in order to place one in position while the other throws the water out above, it being difficult to lay the canvas under a full head of water. The water will press the canvas against the sides and bottom of the ditch, so that none can escape. To remove the cloth, take hold of one end of the scantling and pull slowly upstream.

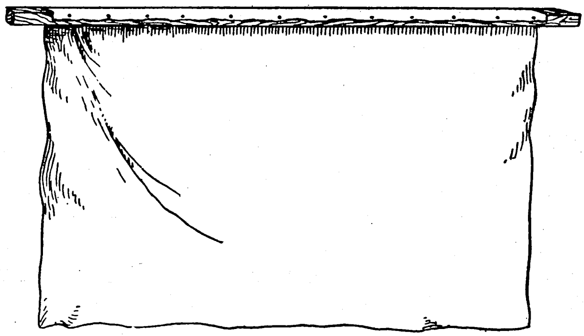
FIG. 9.—The cloth dam.

A metal dam or "tappoon" is on some accounts preferable to the cloth, and it, too, is readily made. Heavy sheet iron is cut into semicircular shape and the straight edge is securely fastened between two narrow strips of wood by carriage bolts which pass through the strips and through holes punched in the iron sheet (fig. 10), or it may be more cheaply made by securely nailing the iron to one side of a single thicker strip of wood, like a piece of scantling. These metal dams are made of different sizes according to the ditch in which they are to be used, their diameter being a little more than the width of the ditch, as the edges must be pushed down a little way into the earth of the ditch banks and bottom. They are placed in the ditch at or near the point where it is desired to turn out the water. These metal dams are also used in the openings in the banks of ditches either to close them when checks are full, or to partly close them and still permit part of the stream to enter the check to balance the soaking away. They are made with sliding gates, as shown in fig. 10, to be used when part of the stream is to be allowed to pass through for any purpose.

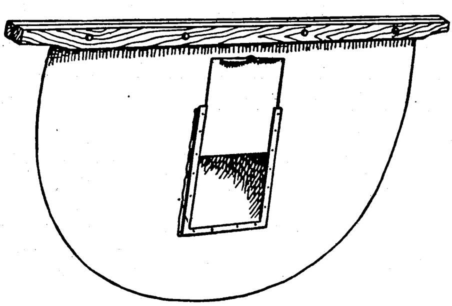
FIG. 10.—The metal dam or tappoon.

Portable wooden dams are also used and are of similar form to the metal dams. They serve a good purpose, but are more cumbersome, more likely to give out, and more difficult to make water-tight except with some shoveling. Wooden dams are, however, of much use in quite small ditches and as gates for handling small outflows into checks, etc. Figure 11 shows a simple wooden contrivance which is widely used. It is made of an inch board 6 or more inches wide and 14 inches long. The lower end is pointed so as to be readily driven into soft ground. Above are two holes about an inch in diameter, one or both to be used according to the flow of water desired. The cut is made in the ditch and the board driven well toward the inside of the ditch to avoid a niche to catch sediment. If a large flow is desired the board is pulled out and afterwards replaced when it is desired to stop or reduce the flow. This device works very well in small ditches.

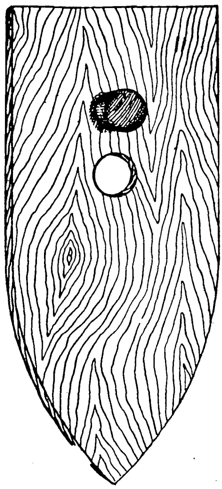

FIG. 11.—Small board dam or gate.

METHODS OF APPLYING WATER.

When the distributing system has been secured methods of application to the land must be determined upon in accordance with the slope of the various irrigation faces and the crops to be grown upon them.

The methods in which application is made in field and garden practice include the following:

(1) Free flooding, or running water without restraint except that afforded by the banks of the laterals conveying it.

(2) Flooding in contour checks, or irregular-shaped inclosures which are determined in size and shape by the inequalities of the surface.

(3) Flooding in rectangular checks, or inclosures which are approximately of equal size and with level bottoms.

(4) Depressed beds, with raised ditches on the levees which hold the water until it soaks away among the inclosed plants—a garden modification of the rectangular-check system.

(5) Ridge irrigation, in which plants are grown on the sides or at the bases of raised ditches—a simple form of depressed-bed irrigation.

(6) Furrow flowing, or running water in one or more furrows between the rows of crops grown in that way.

(7) Raised-bed irrigation, in which the water is taken by seepage and capillary action from a small ditch on each side—a modification of the furrow system.

(8) Subirrigation, or distribution by means of pipes with suitable

outlets, or from blind ditches filled with material permitting circulation of water which will reach the plant roots by capillary action.

(9) Underflow irrigation, by which the ground water is raised by percolation from ditches at intervals of considerable distance—the plant roots being reached directly or by capillary movement.

(10) Distribution under pressure in underground pipes, with standpipes and connections for sprinkling.

FREE FLOODING.

Free flooding is the oldest and simplest form of field irrigation and consists in turning water out upon the land with only the incidental restraint of the banks of the ditches, from which it is released usually

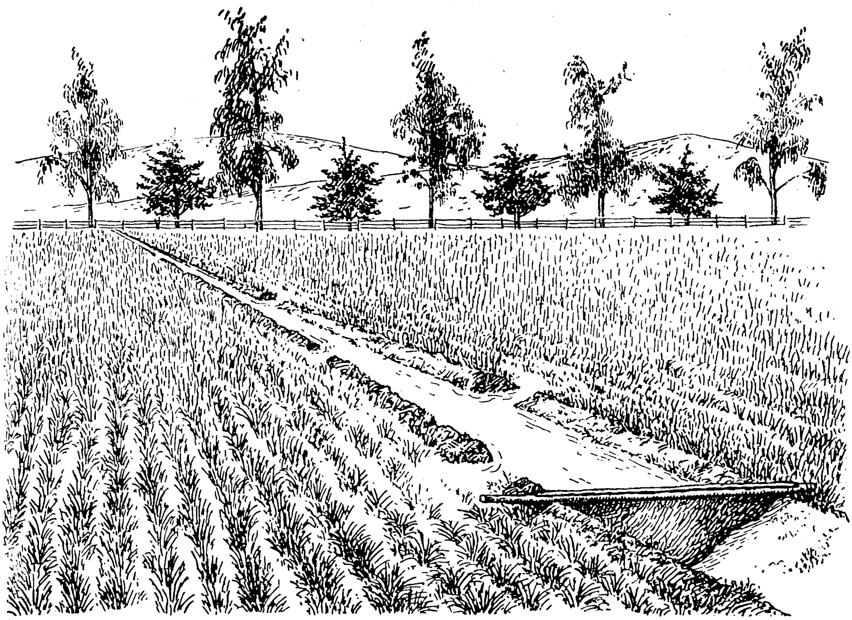

FIG. 12.—Irrigation of a grain field by free flooding, showing cloth dam in position.

by spade cuts at intervals, or by overflowing the banks themselves. On slopes the water may be carried in temporary laterals plowed out approximately on the level, or such laterals may be permanently made and retained, as their low sloping banks need not interfere with the crossing of field machinery. The water has free flow down the slope until the overflow is caught by the next ditch below and flows from it to the lower slopes.

The evenness of the distribution depends in part upon the uniform grade of the land and its freedom from knolls or hummocks and in

part upon the ditches being level; for then as they fill there is an overflow all along the lower banks and all points are reached in the downward movement of the water. On nearly level lands the temporary ditches are made by plowing two furrows thrown away from each other, or by making a furrow with a double moldboard plow. A ditch thus roughed out may need but little cleaning, as very free flow of water is not generally desired.

The water is made to rise in the ditch by damming with earth, a cloth dam, or a metal tappoon, as already described, and is released by cuts in the bank as shown in fig. 12. The irrigator aids the water to reach slighted parts by a little work with a spade here and there. When one section of the field is thoroughly wet the dam is moved to a lower point, and so on. This method of irrigation is best suited for small grain and forage plants, but the difficulty of securing an even spread of water and the amount of work required in handling the water have caused its abandonment in many places for one of the check systems, which require some outlay in first cost, but enable the irrigator to do better work afterwards with a minimum of labor. Where irrigation is not regularly needed a recourse to free flooding may save a crop when threatened by temporary drought. It is also used to some extent in the drier parts of California for winter irrigation of land to be plowed and sown to grain as soon as the soil dries sufficiently for it. Land deeply soaked in winter will mature a grain crop without subsequent irrigation. In this case it is merely a substitute for winter rainfall.

FLOODING IN CONTOUR CHECKS.

Preparing a field for flooding in contour checks consists in throwing up low levees approximately on contour lines, with cross levees at intervals to limit the area of the checks. This method is best suited to land of very gentle slope—land which the eye would judge to be nearly level. The main idea is to restrain the water with levees which will not prevent crossing with farm machinery, and which therefore should not be much more than 1 foot in height and usually less than that. The contour lines showing 1 foot differences in elevation must be some distance apart to leave inclosed areas large enough to make it worth while, and this can only happen on nearly level land. In order to cover the whole surface the levee on the lower line or side must always be a little higher than the difference in elevation between the bases of the two levees, because it is seldom a check can be made brimful, and unless that is done the water would not be set back to the base of the levee on the higher line.

On land with very much slope the checks would obviously be too small and the levees too high and expensive, and they would interfere too seriously with the operation of machinery to make the system

practicable. On the other hand, for nearly level land to be put down permanently into grasses or clover, the contour-check method is constantly growing in favor, and has largely displaced the more elaborate rectangular-check system, which will be discussed later.

Contour checks were formerly used only in connection with lateral ditches leading down the slope in the line of greatest fall, and the levees were run each way from these ditches and the checks filled from gates or temporary openings in the sides of the ditches. This is still done, and is desirable in large fields suitably laid off by a surveyor. For smaller fields, however, and without professional assistance, the laterals can be largely dispensed with and the contour checks filled one from the other with very simple gates to control the flow of water.

It is very common in California to see quite large fields of alfalfa in which all the laying off and levee construction have been done by home skill and with farm teams and tools. The way is, in outline, as follows: Plow the whole field deeply and then begin at the highest point in the field at which water can be delivered by a supply ditch. Use the triangle and run a level line each way from this point to the side of the field. Then return to the supply point and proceed, as described on page 9, to find a point at, say, 1 foot lower elevation. When that is done work both ways from the starting point until that line is carried to the sides of the field. If stakes rising about 18 inches from the surface have been used to mark the line, these will show the top of the levee to be constructed. When the whole field has been marked in this way, loose dirt is gathered up with team and scraper and placed along the levee lines. But only a light skimming is taken, that the surface may be kept free from depressions. If there are knolls and hummocks, they are scraped off and put into the levees and more plowing done here and there as needed. On the sides of the field a continuous levee is made to hold the water where wanted. If the levees are very far apart and the checks, therefore, too large for the stream of water in use, they are reduced in size by running cross levees. After the scraper work is done the levee is shaped into a low, rounded form with hand tools, if the job is a small one, and then the whole field is harrowed lightly so as to even the slopes without dragging down the levees too much. If the dirt has been dumped to the top of 18-inch stakes, the harrowing and subsequent settling will reduce it quite as much as is admissible and still have it set water back to the upper levee a foot higher. On small work much less than a foot difference in elevation is often used and the levees are proportionally lower.

If the checks are to be filled from each other (fig. 13), simple water gates are placed in the levees at such places and distances as one can best judge will facilitate the distribution of the water. These gates are simply boxes, each having a bottom and two sides, with slats across

the top to hold the sides in place. About the middle and on the inside of each side two cleats are nailed just the right distance apart to admit the sliding board or gate to pass up and down between them. These gates are about a foot high and wide in small work, and larger if a large stream of water is available. Where cross levees are used to make smaller checks, more gates are placed in the highest levee, so as to allow the water to flow down in one direction and then in another until all the series have been filled.

Sometimes the contour check system is used without gates by simply allowing the water to fill the higher checks and then flow over the levee into the next, and so on. In this case the levees are quite low and the checks are small.

As a rule the size of the check should depend upon the head or stream of water to be used, and all the appurtenances should be in proportion.

FIG. 13.—Check system, with gates for filling one check from another.

The check should be of such size as to be quickly filled, else the lower side will be saturated and the upper side merely moistened. This method of irrigation is largely used for alfalfa, and haying machinery is readily worked over the levees, which are, of course, covered with the plant as well as the bottoms of the checks. It is also used for grain growing, the levees being plowed, harrowed, and reaped just as are the inclosed spaces.

FLOODING IN RECTANGULAR CHECKS.

Flooding in rectangular checks has been largely superseded by the use of contour checks, except in orchard, vineyard, and garden work. Unless the land is very nearly on a level, much earth has to be shifted in making the rectangular inclosures, and the levees are of irregular heights, while levees on contour lines are practically uniform. There is, consequently, greater difficulty in passing machinery over them. For orchard and vineyard, where the rectangular arrangement of the

trees and vines continually interferes with contour work, rectangular checks are widely used where the character of the soil calls for flooding.[1] They may be large, inclosing quite an area of vines or trees, or they may be very small, even but 10 feet square. This, of course, depends upon the grade of the land.

For the growth of garden truck, also, the rectangular arrangement accords with the rows in which such products are grown, and fig. 14 represents a typical scene in a market garden operated on this system. In such cases the laying off is temporary, as when the crops are gathered, or at the end of the season's succession of crops, the levees are plowed down, and then the whole field thoroughly plowed and harrowed and the levee system restored, sometimes by backing furrows each way and finishing with hand tools or by using a ridger, etc., pictured and described in a previous farmers' bulletin.[2]

In small gardens it may be thought better to retain the levee system and work the bottoms of the checks with fork or spade, according to

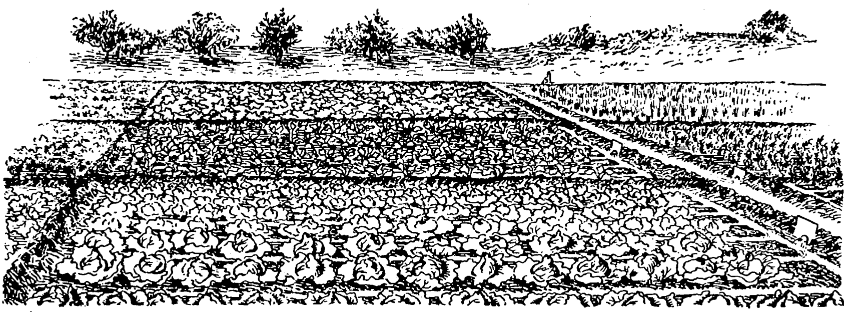

FIG. 14.—Rectangular checks, with arrangements for filling from a lateral ditch.

the usual methods of hand-power gardening. In field work on level land the checks may be so large that teams are used inside the levees, and in that case the irrigation arrangements are permanent. Whether, however, the levees be temporary or permanent, the water is applied about the same way already described for the contour check system.

In the most satisfactory work in rectangular checks the check bottoms are approximately leveled by scraping the hummocks into the low places, using surplus dirt for the levees. Grading or leveling is very desirable and the initial cost is returned many times over in the ease and satisfaction with which the water is evenly distributed inside the check. This is often done by running small furrows between the plants in the check bottoms so that the water is led this way and that until all the plants are equally supplied.

[1] See U. S. Dept. Agr. Farmers' Bul. 116.

[2] See U. S. Dept. Agr. Farmers' Bul. 116, pp. 30, 31.

THE DEPRESSED BED.

The depressed bed, largely used in the growing of vegetables and small fruits, is really a form of rectangular checking. In this case, however, the levees are widened so that they are not merely boundaries to confine the spread of the water to the inclosed areas, but they are also made to carry water to these areas by small raised ditches which are made upon their tops. Fig. 15 shows an arrangement of this kind. It is best for light, sandy loam, which has slight retentiveness and therefore loses moisture rapidly both by drainage and surface evaporation and must be frequently irrigated.

Shallow rooting plants like strawberries, which would perish by the methods of irrigation employed for them on more retentive soil, and which will be described presently, make very satisfactory growth and have a long fruiting season if grown in a depressed bed, especially if they are mulched well with rotten straw or coarse manure and the

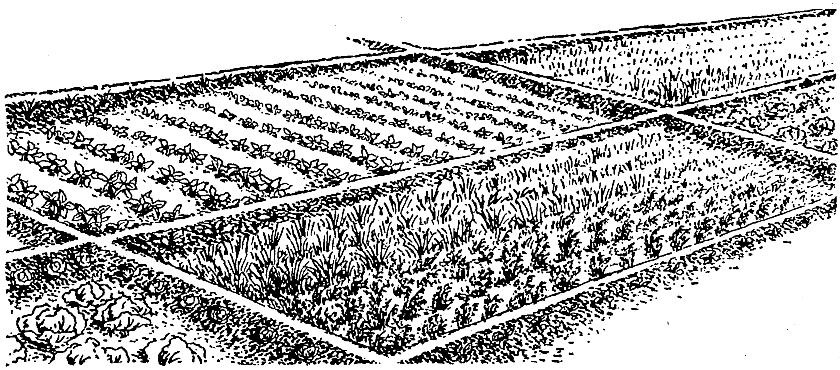

FIG. 15.—Depressed bed for vegetables and strawberries.

water allowed to distribute itself under this cover by admission from the raised ditch at several points at the same time. The ditch at the surface level is much less satisfactory in such work; consequently it is run along the top of the levee. This arrangement is particularly adapted to very light soils, as stated, and especially in the hotter parts of the arid region, where water has to be applied once or twice a week to shallow rooting plants and where the shading of the ground by a mulch lowers its temperature and protects the roots from heat, which would be apt to destroy them in spite of the frequent use of water alone. This recourse takes the place of mulching and sprinkling and is vastly better for a hot, arid locality. The sprinkled water flies off from the mulch with great rapidity and much water is used with little benefit to the plant, while the filling of the depressed bed from the ditch and spreading the water through and under the mulch is very economical of water and of most direct advantage to the plant.

For the hot, dry season of the year, in places where there is no

danger of supersaturating the soil, the depressed bed is available for all kinds of vegetables and small fruits and flowers, and the use of this system is really the secret of success in growing them in some regions.

It is quite widely employed also by market gardeners and others, even where heat is not excessive, but where a light, sandy soil predominates. A prominent example of this is in the sand hills south of San Francisco, where the vegetable growers, who are largely natives of the Mediterranean countries, have transformed large areas of hillsides into terraces and on these have arranged depressed beds, chiefly of quite small areas, and are growing large quantities of garden truck. The water is raised by windmills and pumps from wells in the low places and delivered into small flumes which run from the windmill towers to the opposite hillsides, supported by very light, high trestles. The water is then, after supplying the highest terrace, conveyed most ingeniously by troughs or small ditches from terrace to terrace until all the beds have been filled. The terraces are so narrow and the beds on them so small and irregular in shape that depressing them and filling them from time to time seems about the only available way to make use of such little corners of leachy soil. The system calls for an immense amount of hard hand work, but the Mediterranean immigrant seems born to it.

DITCH-BANK IRRIGATION.

A simple form of depressed-bed irrigation, and one which is readily available for home garden work in the arid region, may be called "ditch-bank irrigation." It aims to use the water percolating from a raised ditch, which will moisten the slope of the bank and the soil for a certain distance outward from its base. Its prototype is perhaps the old permanent ditch of the Spanish settlers, which was opened out from a stream on a grade favoring a slow flow, and whatever land on each side was thus moistened was used for a few beans, onions, and peppers, which were about the only vegetables these settlers required. In the depressed-bed system the banks of the water-carrying levees are usually set full of quickly maturing vegetables.

Ditch-bank irrigation consists in a sort of a combination of the old Spanish practice with some part of the more systematic depressed-bed practice of the Italian market gardeners. The method is to plow in deeply a good covering of manure and harrow thoroughly until the land is well settled. Then find a direction in which the land is nearly level and back two or more furrows to form a ridge. Rake over the surface, shaping up the ridge evenly, and on its crest mark out a narrow ditch with the hoe. Connect the head of this ditch with the water supply and run in a small stream, aiding its course with a little cutting and filling until it runs evenly the whole length of the ridge. This will settle the ground, and some smoothing with the rake will be

needed. When the ground is in good shape, sow the seed or set the plants along the top and sides of the ridge and along the base also. If the soil is not too leachy, the water will percolate slowly and evenly and moisten the soil without cropping out on the surface. The ridges can be multiplied and distribution of water to their several heads be arranged with troughs or otherwise, and the overflow at the ends can be led away to trees or clover patches. Water can be run from time to time to these channels as required, and the banks and bases can be used for a succession of vegetables.

The method requires work and care to arrange the grade, etc., in the first instance, but for the rest of the season the irrigation is automatic, though, of course, much hand hoeing will have to be done among the plants, for the constant presence of moisture and manure makes large weeds as well as vegetables. It is surprising, however, how large a home supply of vegetables in variety can be grown on 200 or 300 feet of ditch bank while all the rest of the landscape may sear.

IRRIGATING IN FURROWS.

The furrow system is the simplest, cheapest, and most widely used method of irrigating all field and garden crops which can be grown to

FIG. 16.—Field irrigation by the small-furrow system.

advantage in rows (fig. 16). It is practicable on surfaces differing widely in slope and in soil characteristics. If the slope be not too sharp to carry a small stream without much cutting, the rows are run straight down the grade from the lateral or flume running along the crest or ridge of highest ground; if the descent be too rapid, the rows are run diagonally from the supply ditch at whatever angle gives the proper slope. The distance a stream in a furrow can be carried successfully depends upon the nature of the soil and the size of the stream. The coarser the soil the larger the stream or the shorter the distance.

With shallow-rooting plants, like those comprising most field and garden crops, a larger stream and a shorter run are used than in irrigating fruit trees, because it is desirable to have the water spread freely nearer the surface. For this reason, and to secure more even

distribution over the field, a second lateral ditch or flume is taken across the slope at a distance of 40 rods or so from the first, and a lower length of furrows is fed from this secondary source.

The whole system, then, on a broad, gentle slope would consist in a supply ditch passing down the slope with laterals at right angles or on contour lines, from which the water is admitted to the furrows made with a small double moldboard plow between the rows of plants. The lateral, whether it be ditch or flume, should be as nearly level as possible and kept well filled with water, so that the amounts discharged at the openings shall be nearly equal. The openings are simply cuts in the side of the ditch, each one supplying several furrows, and divided with hoed or shoveled ways in the earth. If the flume is used, the water is taken out through holes bored at proper intervals in the sides, and if the slope along the line of the flume is too rapid, the lengths of the flume are leveled and "drops" arranged for the water

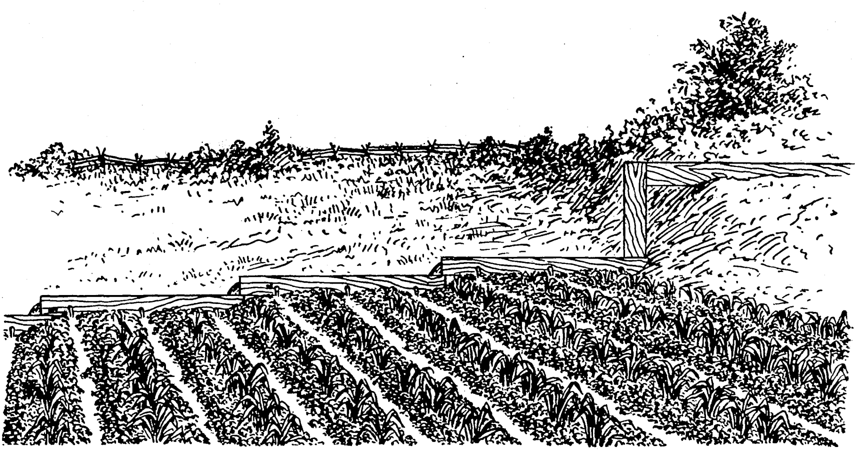

FIG. 17.—Furrow irrigation on a slope with stepped flumes and drop.

from one length to the next. Thus a series of flume lengths, each one level, may be carried down quite a slope by steps (fig. 17), and give equal discharge of water for all the furrows of a wide field.

There are very many ways by which water may be brought to the heads of the furrows, such as movable troughs, canvas hose, etc., according to the local conditions and the ingenuity of the operator. If the soil is not too porous, the furrow method is a good recourse when a small stream of water running continuously has to be used; for it is easy to arrange so that attention need be given to it only at intervals and the irrigator can proceed with his other work.

This furrow irrigation operates on a flat-culture basis. As soon as the ground dries sufficiently a cultivator is used between the rows and the ground leveled and pulverized as thoroughly as possible to prevent surface evaporation and baking of the soil. When another irrigation is needed new furrows are made, as before.

RAISED-BED IRRIGATION.

A very important modification of the furrow system is the raised bed, which, under certain circumstances, is of great value in the vegetable and small-fruit plantation. The raised bed is an elevation between two irrigating furrows. The field is laid off in narrow lands and several furrows thrown together so as to bring dead furrows about four feet apart, making long beds extending down the grade with their surface raised several inches above the old level. The motive is to arrange a plant bed with a water course on each side and below its surface level (fig. 18). The whole plan is just the opposite of the depressed bed with raised ditches already described, and is obviously to meet quite different conditions. It is especially suited to a rather heavy soil in which water will move well laterally, rise well, and be retained. Irrigation is accomplished by holding water for a time in the ditches. Where the ground is sloping it is held in levels by dirt dams or by the cloth or metal dams already described, placed at intervals as required to raise the water nearly to the ground surface.

FIG. 18.—The raised-bed system for vegetables and small fruits.

The arrangement has several advantages for the market gardener and is largely used by those of foreign birth, who rely upon hand work and desire to carry as many plants as possible per acre; for their rents for rich land near cities are usually high. It enables them to plant in close rows and in starting young plants it gives standing water alongside, which they can easily flirt out with a pan or shovel when they think a little sprinkling is desirable. The Italian gardeners have a knack of doing this which is very interesting.

The chief advantages, however, are the distribution of water beneath the surface, which lessens the need of surface cultivation, and when the vegetables are well grown obviates the decay which comes to foliage by contact with a moist surface. The same is true of the use of raised beds for strawberries when grown on the heavier loams or when the light, shallow loams overlie hardpan and require frequent irrigation.

Another very important advantage of the raised bed lies in its adaptation to growth of vegetables and strawberries during the rainy season of semitropical climates. Not only is the raised bed more

responsive to the greater warmth which comes to the air at intervals, and consequently promotive of winter growth of vegetables, but it also escapes the supersaturation which long rains may occasion. The deep ditches then act as open drains for the escape of surplus water. The system would seem to be widely available where there exists both the need of irrigation and the danger of excessive rainfall, according to varying weather conditions.

SUBIRRIGATION AND UNDERFLOW.

Subirrigation is the application of water under the surface by a system of conduits. It has received so much thought and outlay and has returned so little satisfaction that it must be looked upon as a horticultural *ignis fatuus*, and only a passing reference need be given to it. Various available publications[1] describe its different phases. It seems fair to conclude that satisfactory growth is secured with less water by subirrigation than by surface distribution, but it is done at an outlay which is unwarranted either by the cost of water or by the value of the crop. Results of greenhouse experiments are more satisfactory than those from open-air work. Even if even distribution could be had from any arrangement of underground pipes, which seems doubtful in view of wide experience, it still remains true that for shallow-rooting plants in open soils the water is applied at too low a level.

It also appears that the escape from the surface cultivation is of doubtful advantage, contrary to the claims of advocates of subirrigation, and that thorough surface stirring, which is an indispensable accompaniment of surface irrigation, is worth all it costs through the superior thrift which it induces. It seems a fair conclusion from present knowledge that subirrigation is practically unattainable because of cost, inequality of distribution, etc., and possibly would be undesirable even if these prohibitions were removed.

Underflow irrigation is quite different from subirrigation, though the former often goes in local parlance as "natural subirrigation." Underflow is a natural movement of water through the subsoil outward from streams or downward from catchment areas toward the country drainage. Underflow irrigation consists in reinforcing this flow, or in imitating it by bringing water to follow the same course of distribution.

It is an available method, first, where the ground water is naturally near the surface and irrigation water is easily obtained in large quantities; second, where an open soil through which water spreads readily is found resting upon an impervious hardpan, or slightly pervious clay, which prevents loss of water by percolation. In both of these

[1] Subwatering in Greenhouses, Farmers' Bul. 78. Irrigation in Fruit Growing, Farmers' Bul. 116. Surface and Subirrigation Out of Doors, New Hampshire Sta. Bul. 34.

conditions the method of irrigation is the same, viz, to open deep furrows at considerable distances apart and keep them filled with water for a considerable time, so that it may soak away in large quantities. The addition will in the first case raise the ground water so that it will rise by capillarity to the plant roots; in the second case the irrigation water will spread through the free soil, flowing along the surface of the hardpan or clay, and will thus become available to plant roots. These methods are most apt to be useful with deep rooting trees and vegetables, but they are also used, where the conditions are favorable, for grains and garden crops.

IRRIGATION BY SPRINKLING.

Irrigation by sprinkling is a method which, so far as the writer knows, is not pursued for any commercial purpose in the irrigated regions of the country. It does, however, sustain itself on the ground of commercial advantage in the Eastern States, as has recently been shown by Professor Vorhees,[1] and the data which he presents should be carefully considered by those who contemplate recourse to irrigation as a protection to high value crops against occasional deficiency in summer rains.

CHOICE OF AN IRRIGATION METHOD.

In the discussion of the different methods of applying water incidental mention has been made of the particular adaptations of each. It may be further suggested that the choice of method is to be made in accordance with several conditions:

(1) The slope of the land. This is obviously a ruling factor, but its relation to the different methods described has already been discussed in connection with each method.

(2) The character of the crop. Small grains and forage crops which are best grown from broadcast sowing are open only to flooding or sprinkling, and the latter is probably out of the question because of cost of outfit and attendance.

(3) The character of the soil. Soils naturally very open or loose, or market-garden soils rendered very loose by the constant and deep working in of coarse manures, favor such rapid percolation that even distribution through the soil mass can be had only by covering the surface rapidly with a uniform sheet of water. Under such conditions, also, flooding and sprinkling are the only practicable alternatives. The fact that sprinkling is not practiced to any extent in regions where much irrigation is done invites the conclusion that some form of flooding is better. On the other hand, for soils which take water slowly and distribute it well, both laterally and vertically, the furrow system, distributing water between long rows of plants, is

[1] Irrigation in New Jersey, U. S. Dept. Agr., Office of Experiment Stations Bul. 87.

best for plants which are profitably grown in rows, and on land of a grade which does not force too rapid flow of water.

(4) The labor requirement. The largest area can be evenly moistened with least labor by the contour check system and by the furrow system. Each is superior to all others in this respect for the conditions of land and crop to which it is adapted. The labor requirement in preparation of the ground has been so reduced by improved grading and leveling devices and by using permanent levees which allow all the ground to be cropped instead of counting the levees waste land, that the first cost of putting the land in shape for flooding in contour checks is but a slight addition to the grading necessary to remove the knolls and sags which is necessary in preparation for the furrow system.

(5) Ease of cultivation after irrigation. The desirability of stirring the soil surface after irrigation has already been mentioned in discussing methods of applying water. It is a means of checking evaporation and consequent waste of moisture, but it is more than that. The effect of irrigation is to draw the soil particles together, and if it be a soil containing much clay there is compacting followed by cracking as drying proceeds. In the old practice this condition was taken as a demand for more water, and another irrigation was given, which merely aggravated the trouble and plants came to distress. More water was used than necessary for good growth, and still thrift was not secured. The remedy is cultivation as soon after irrigation as the soil is in condition to break readily and become mellow and friable. Except, perhaps, where a mulch is used, cultivation is essential to the best soil condition, and consequently to the most satisfactory growth of the plant. It follows, then, that methods of irrigation which facilitate subsequent cultivation are to be preferred wherever the ground slope and the character of the soil favor them. Of all methods, that of irrigation by furrows between straight rows of considerable length is obviously best for cultivation with horse tools, and is adopted by American growers wherever practicable. The foreign-born grower has a traditional preference for hand work, and is more apt to choose one of the flooding systems even where the furrow method would operate well. The furrow method can be used in a wide range of soils—in fact, as has been said, on all likely to be encountered except coarse, sandy loams, in which water sinks almost as fast as it is admitted to the furrow and makes very little lateral spread. In such soil a plant may suffer severely although it is very close to a furrow. For the distribution of the water evenly and to apply it to the upper soil where the shallow-rooting plant can use it, one of the flooding systems must be used, and cultivation must be well done at the earliest arrival of suitable soil condition. Although such a soil is not subject to baking and cracking it becomes "cemented," as the local term is, and then the effect of irrigation is of very short duration.

WHEN SHOULD WATER BE APPLIED?

This is a question to which a definite answer can not be given, except that water should be applied before the plant shows distress. It therefore follows that the time when water should be applied can not be determined by watching the plant. Thrifty growth should characterize a crop from start to finish. Even a small degree of drought will induce some plants to enter upon maturing processes and then a new moisture supply may start an undesirable new growth rather than promote the old.

Many irrigators decide when their crops should be watered by an examination of the soil. A rule which has been frequently given is to take a handful of earth from a few inches below the surface and press it in the hand. If, when released, the soil holds together in a ball, and shows the marks of the fingers, irrigation is not necessary, but if it does not hold together water should be supplied. The time when crops should be irrigated depends, then, upon the nature of the crop, the soil, and the weather, so that no dates can be suggested for any locality.

The best sources of information on local practices are the agricultural experiment stations in the different States and Territories, which are now very properly giving much attention to this subject.

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